

 **CANMET**
Energy, Mines and Resources, Canada

**Pre-Engineering
Assessments of Enersolve
Demonstration Projects**

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February 1, 1983

SNC Inc.

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Mr. A.C.S. Hayden
Department of Energy, Mines
and Resources
CANMET
Energy Research Laboratories
555 Booth Street
Ottawa, Ontario
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Dear Mr. Hayden:

Re: Pre-Engineering Assessments of Enersolve Demonstration Projects

We are pleased to submit six (6) copies of the final report for
Phase I of the project in accordance with the contract.

We trust this report meets your approval.

Yours truly,

Z.A. Siddiqi
Project Manager

ZAS/mb

Encl.

cc: Mrs. Paula Green
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TITLE

PRE-ENGINEERING ASSESSMENTS OF ENERSOLVE DEMONSTRATION PROJECTS

FINAL REPORT

BY

SNC INC.

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SUMMARY

The pre-engineering survey, which was carried out, is the Phase I of a 4 phase Enersolve demonstration programme aimed at demonstrating energy conservation by effecting improvements in the operating efficiency. at the specific plant site.

The Miron Cement Company's Montreal plant was selected as a specific site because the cement industry is known to be one of the most energy intensive and offers a high potential for energy conservation.

The testing was carried out at this site to establish data on fuel use, combustion and heat efficiencies of the kiln, the sensible heat recovered in the clinker cooler and to prepare heat balance for the kiln. Conceptual equipment upgrading and retrofit procedures to improve the heat efficiency of kiln is prepared. The capital cost for upgrading and retrofitting, and detailed engineering cost have been estimated. Schedule for detailed engineering, procurement and installation has been prepared. Based on the potential energy savings to be achieved by upgrading and retrofitting the facility, 47% Return on Investment (ROI) is anticipated. It is recommended that the suggested upgrading of the facility be carried out.

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1.0

INTRODUCTION

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1.0 INTRODUCTION

The present work was carried out for CANMET, Energy Research Laboratories, under the Contract No. 17SQ.23440-2-9055-4 through DSS, Ottawa, entitled "Pre-Engineering Assessments of Enersolve Demonstration Projects".

The ENERSOLVE program under which the present project was carried out is concerned with increasing the efficiency for the utilization of oil and gas in industrial boilers, kilns, furnaces, etc. The objective of the present investigation was to first identify oil and/or gas burning industrial units which show potential for energy conservation. The industries which are the most energy intensive are cement and utilities industries. The cement industry consumes about 120 kWh of electrical power per ton of cement and consumes about 83 to 170/kg of fuel oil per ton of cement. Currently for the cement industry, the energy cost amounts to more than 40% of the total production cost. Based on these data, the cement industry was selected as the industry which shows the most potential for energy conservation.

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The study was site specific in nature. The specific site selected for testing was the Miron Cement Company plant located in Montreal, Quebec. The Study is divided into four phases. These phases are as follows:

- Phase I - Present pre-engineering survey
- Phase II - Detailed engineering plan for modification and costs for Phase III and IV
- Phase III - Retrofit of equipment and commissioning and acceptance by the owner of upgraded systems
- Phase IV - Nine month monitoring and maintenance of upgrade facility

This report deals with Phase I of the work. In the present work, a pre-engineering survey was carried out, which involved:

1.0 INTRODUCTION (cont'd)

- a) Identification of the site-specific oil or gas burning industrial units which show potential for energy conservation by effecting improvements in the operational efficiency and which is available for testing and upgrading. The Miron Cement Company's Montreal plant was adjudged to be the ideal specific site.
- b) Conducting site investigation and tests to establish data on fuel use, combustion efficiencies, process load characteristics, etc.
- c) Conceptualize equipment upgrading and retrofit procedures to improve efficiencies and estimate cost/benefit impact.
- d) Estimate the project costs at the site for implementing modifications and monitoring the performance.

The heat balances were carried out and the areas where energy savings could be achieved were identified. The plan for upgrading and modification is prepared.

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FACILITY DESCRIPTION

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2.0 FACILITY DESCRIPTION

The Miron Co. Inc. cement plant is located in Montreal, Quebec. The plant was erected in 1959 and started production in 1960. The kiln which was started in 1960 was the subject of the present investigation.

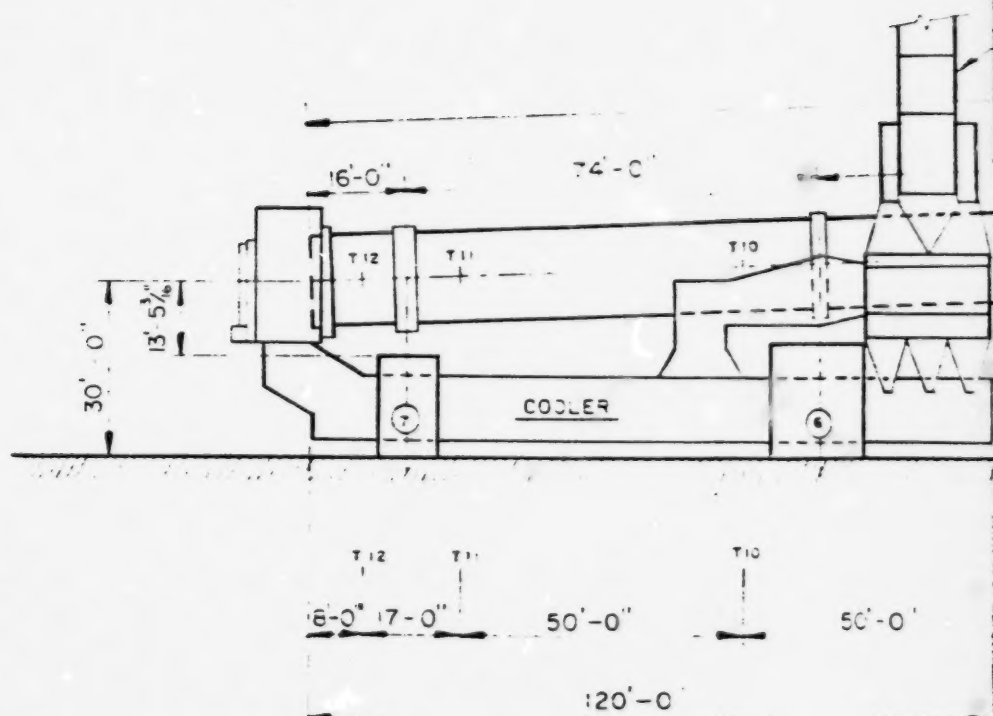
The kiln is a dry process long kiln with the nominal production capacity of 1,500 metric tons per day. The total length of the kiln is 550 ft. The internal diameter of the kiln at 107 ft length, is 14 ft and at 443 ft, it is 13.5 ft. The maximum rotating rate of the kiln is 0.3 minute/rotation, the minimum rotating rate is 1.33 minutes/rotation. The kiln is currently run at the rate of 1.24 minutes/rotation. Drawing 1 presents the schematic of the kiln. Appendix A gives the design data for the kiln system which includes cooler, crusher, electrostatic precipitator, water atomizer, ID fans, cooler air fan, kiln chain system and primary air fan.

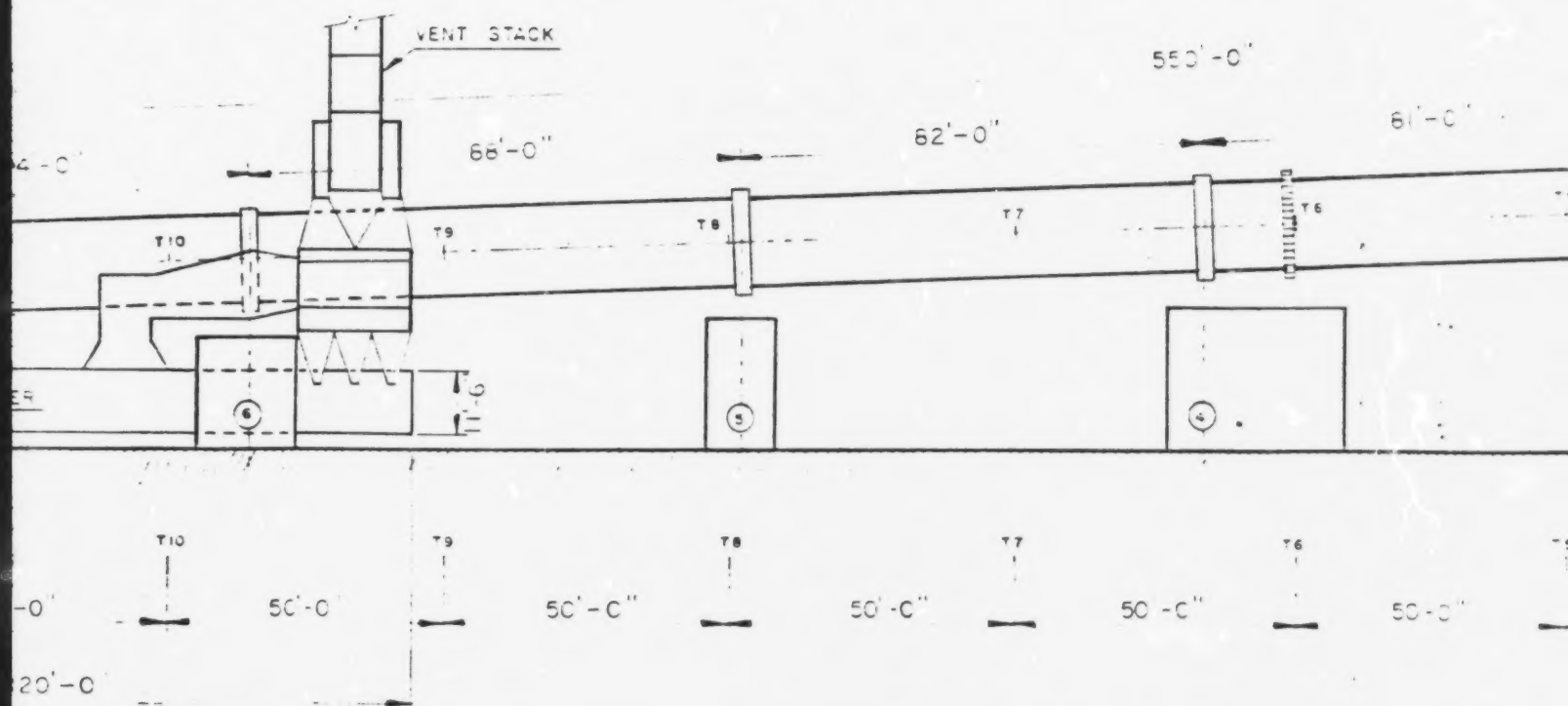
The cooler, manufactured by Allis-Chalmers, is a air quenching reciprocating type cooler. It has two sections, each 60 ft long. The nominal capacity of the cooler is 1660 tons clinker/day. This cooler was equipped in 1981 with a gravel filter equipped with four cyclones followed by 14 gravel chambers with 130mm layers of gravel.

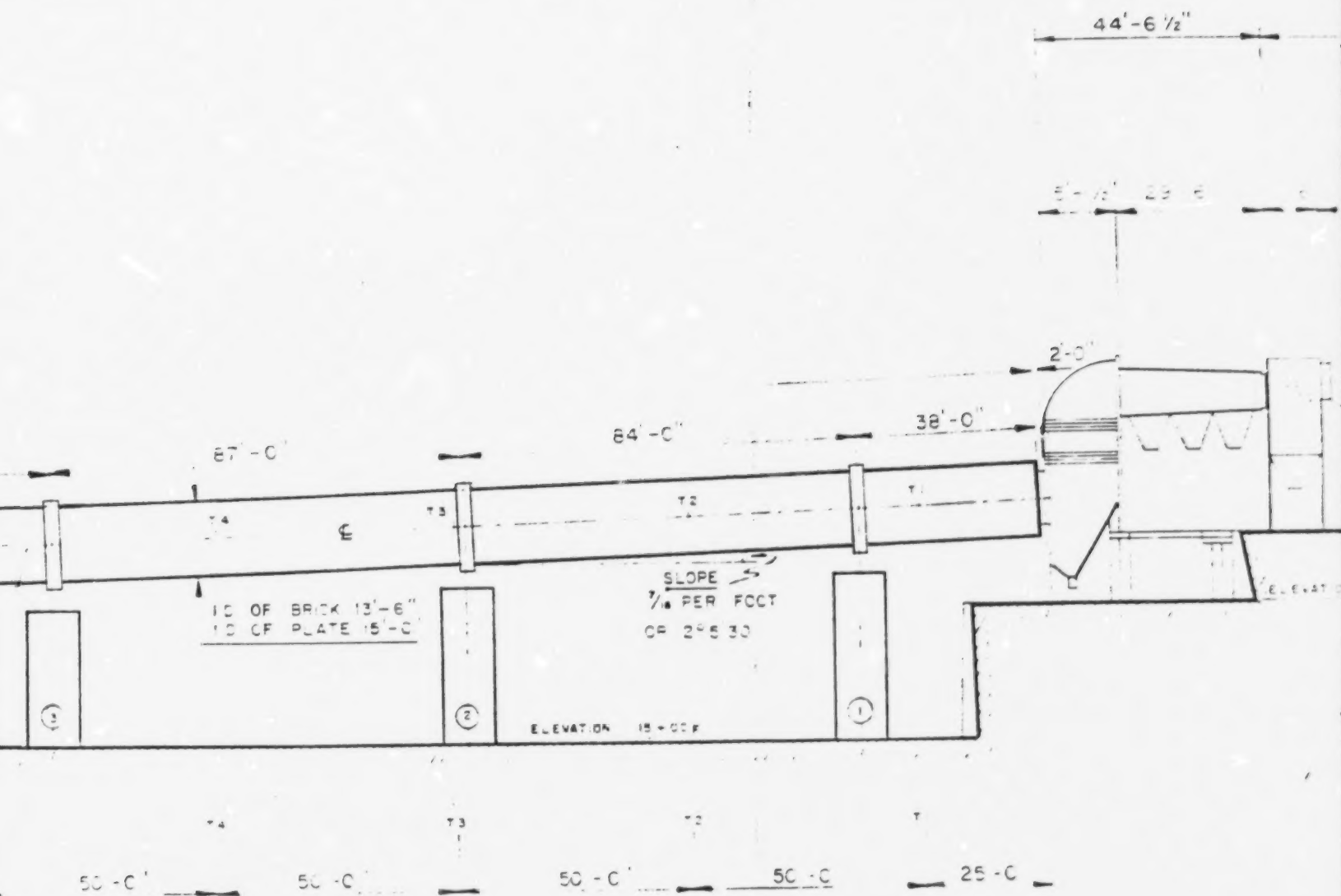
The crusher is a hammer mill type 7 1/2 ft wide. The electrostatic precipitator, manufactured by Western Precipitation Co., is a RWS Cottrell, preceeded by a multicyclone type. The operation is automatic with transistomatic controls.

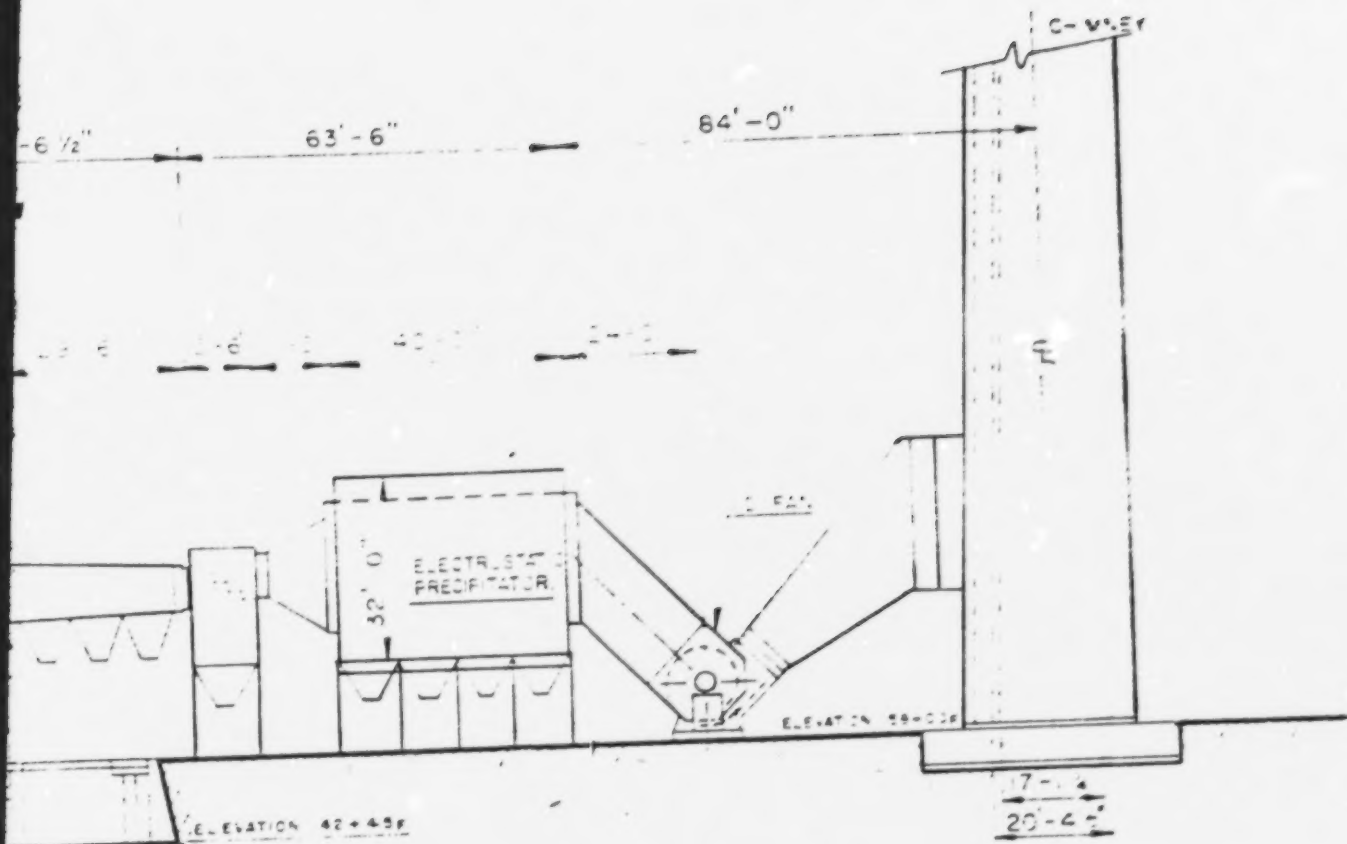
There are two ID fans with 567 RPM and 230 SHP. They can draw 2000,000 CFM of air and produce a draft of 6" static pressure.

The kiln chain system is divided into two areas separated by a 7 ft chain free area. The first chain area is formed by 31 rows of chains, each row separated by a distance of 12 7/8" from each other. The second chain area is formed by 15 rows of chains, each separated by 12 7/8" distance.









T = SHELL TEMPERATURES WELDING POINTS

6711 - 0000 - 4900 - 0001 - 00	
DRAWN BY C. W. 1, 80	SCHEMATIC DRAWING-1
APPROVED	
DATE MARCH 1967	
SCALE 1/2" = 1'-0"	

3.0

TESTING PROCEDURE

END

3.0 TESTING PROCEDURE

Determination of the heat efficiency of the kiln was the aim of these tests. In order to determine this, the kiln heat balance was performed on December 2 and 3, 1982.

At the onset, the oil flowmeter and other kiln instruments were checked and recalibrated wherever found necessary. During the 24 hours, all the kiln operating data, such as kiln RPM, kiln feed temperature, fan RPM, kiln shell temperature, fuel feed rate and cooler fan motor RPM were measured. The solids and gaseous samples were drawn and their elemental analyses were carried out. The kiln feed rate, dust flowrate and the clinker production rates were also measured.

The gas flow rates were measured using calibrated flow meters. The fuel oil flow rates were measured by noting the tank level readings. The solid flow rates were measured using the weighbridge and stopwatch. The gas streams were analyzed using the orsat apparatus. The elemental analysis of the fuel oil was determined at the CANMET laboratories in Ottawa. The composite chemical analyses, the physical analyses and the mineralogical compositions of solid material entering and exiting the kiln were performed every two hours. The samples were sent to an independent laboratory for carrying out the same tests. Also, LOI (Loss on Ignition) tests for the feed samples were performed.

The air flow rate to the kiln was varied and the flue gases leaving the kiln were analyzed. The rise in the fume chamber temperature after shutting down the cooling water spray was determined. The pitot tube measurements to determine the gas flow rate of the cooler were taken.

3.0 TESTING PROCEDURE (cont'd)

The tests carried out were of higher precision than the routine tests carried out at the plant. The ID fan data sheet could not be located. Hence, data for the ID fan performance has been estimated. Also, there might have been some instrument and human error incurred in collecting data. Because of these limitations, the data collected is within $\pm 5\%$ accuracy.

4.0

RESULTS AND DISCUSSION

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4.0 RESULTS AND DISCUSSION

The operating data for the tests carried out on December 2, 1982 are listed in Appendix B. The chemical analyses, physical analyses and the modules and mineralogical composition of the raw feed, dust and clinker are given in Appendix C. The material balance calculations are given in Appendix D and detailed heat balance calculations are given in Appendix E. Table 1 gives the summary of the heat balance applied on the kiln system.

4.1 General

There are four areas in the rotary kiln where by carrying out proper modifications, the heat efficiency of the system can be improved. They are:

- Combustion system
- Kiln chain system
- Heat recovery in the cooler
- Kiln shell losses

Each of these areas are discussed as follows:

4.2 Combustion System

In the cement industry, the optimum ratio of secondary air to total air is 0.9. In the present case, as it can be seen from Appendix E, this ratio is 0.55. This indicates that there is a higher amount of primary air in kiln than necessary for the efficient operation of kiln. The primary air is at ambient temperature while the secondary air which comes out from the clinker cooler is at an average temperature of 870°C (Appendix B). Hence, by increasing the secondary air in the kiln, sensible heat recovered from the clinker can be effectively utilized.

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TABLE 1
RESULTS OF THE KILN HEAT BALANCE

REFERENCE	DESCRIPTION	HEAT IN KCAL/KG CLINKER	HEAT OUT KCAL/KG CLINKER
	INTAKE HEAT		
F	Fuel oil: combustion	918.71	
	sensible heat	5.03	
E	Air: primary and tertiary	2.12	
	secondary	202.02	
E	Water spray fluids	0.47	
E	Raw feed	12.91	
E	Recycled dust	10.41	
	OUTGOING HEAT		
E	Clinker: heat of formation		352.00
	sensible heat to cooler		345.80
E	Dust: discarded dust		8.62
	outcoming recycled dust		18.11
E	Fumes		307.45
E	Shell losses through convection and radiation		94.55
E	Heat absorbed in spray		27.70
	Undetermined		- 2.56
	TOTAL HEAT KCAL/KG CLINKER	1151.67	1151.67

4.2 Combustion System (cont'd)

The saving in heat by increasing the ratio of secondary air to total air from 0.55 to 0.9 is estimated to be 50 kcal/kg clinker (Appendix E). The large amount of primary air in the kiln is because of a leak in the kiln which enables external air to leak into the kiln. This air is treated as primary air, resulting in the loss in the efficiency.

The optimum amount of excess primary air for the complete combustion of the fuel in the burner is 3.5 to 7.5%. Decreasing the primary air and increasing the secondary air will increase the flame temperature and hence, the heat transfer by radiation, which is the main mode of heat transfer in the kiln, is improved. Furthermore, by decreasing the primary air, the flame becomes incandescent and thereby, increasing the emissivity and improving the heat transfer in the kiln. The saving in heat because of this factor cannot be quantified at this stage, however, it is estimated to be 50 kcal/kg clinker.

Figure 1 shows the schematic of the kiln and the clinker cooler. It can be seen from Figure 1 that exhaust air comes out from the colder section of the clinker cooler and hence, it is at lower temperature. The exhaust air in the present case has an average temperature of 140°C. For the reasons mentioned above, increasing the secondary air in the kiln is very attractive, however, the secondary air cannot be increased indefinitely because then, the low temperature exhaust air will start getting mixed with the secondary air and the marginal gain in the heat saving will decrease. Hence, there is an optimum condition which has to be achieved.

Some false air is entering the kiln through the leaks at the joints of the kiln, decreasing the heat efficiency of the kiln. However, some of these leaks are unavoidable.

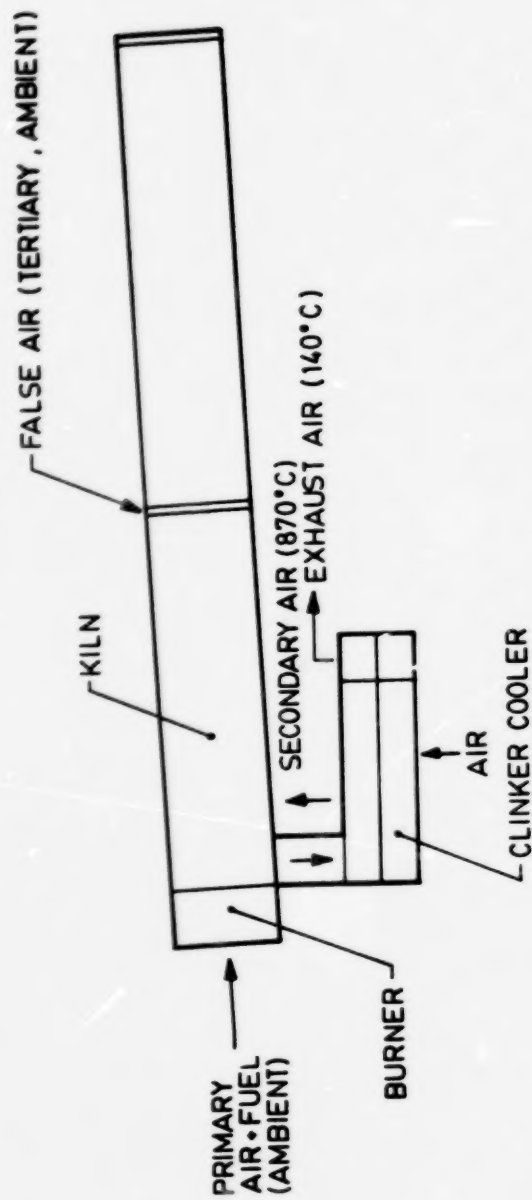


FIG. I SCHEMATIC OF KILN + COOLER

4.2 Combustion System (cont'd)

The amount of air through the kiln should be properly controlled because a very less amount of air in the kiln would lead to incomplete combustion of fuel and thereby reduce the fuel efficiency and a very small amount of air flow through the kiln would reduce the heat transfer co-efficient. However, a very high flow rate of the air through the kiln would result in very high heat losses in the flue gas and improved heat transfer because of increased flow rate may not be able to compensate for the loss. All these factors will have to be considered and an optimum condition will have to be determined in Phase II of the study.

4.3 Kiln Chain System

The kiln chain system improves the heat transfer through the kiln. In the present case, kiln heat transfer rate can be improved significantly by revamping the kiln chain system. By changing the system to the latest available chains, the heat transfer through the kiln can be significantly improved. The exact amount of saving will have to be determined during Phase II of the study.

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4.4 Heat Recovery in the Cooler

The heat balance calculations in Appendix E indicate that the clinker cooler is operating inefficiently. The exit temperature of the clinker from the cooler is 156°C. An efficient cooler should be able to cool the clinker to at least 70°C. Thus, by revamping the clinker cooler, some amount of heat saving can be achieved though this amount may not be very significant. The detailed calculations are given in Appendix E.

4.5 Kiln Shell Losses

The heat losses through the kiln shell are determined to be 95 kcal/kg clinker. These losses are because of radiation and convection. In the

4.5 Kiln Shell Losses (cont'd)

present case, the shell losses are reasonable and cannot be avoided. However, for every system they will differ and for other kiln, they will have to be determined independently.

These are the four areas where by carrying out proper modifications, the heat efficiency of the system can be improved. In the present case, by increasing the secondary air in the kiln and by improving the combustion efficiency, the estimated heat saving that can be achieved is about 100 kcal/kg clinker. This saving, when translated into dollars by using the fuel oil price of \$35 to \$37 per barrel, amounts to about \$1,000,000 for a plant with the capacity of 500,000 tonnes of clinker per year. In the present case, the kiln specific fuel consumption is 918 kcal/kg of clinker which compares very favourable with the lowest American average of 997 kcal/kg clinker for dry long kilns. In Canada, there are currently 18 wet and 6 long dry kilns with specific fuel consumption of 1200 kcal/kg clinker. If all these are retrofitted to modify the kiln, as carried out by the principal investigator at the Miron Co., the specific fuel consumption of the kilns can be brought down to 950 kcal/kg clinker and as a result achieve substantial savings in fuel.

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5.0

ESTIMATE OF THE PROJECT COST
FOR IMPLEMENTING MODIFICATIONS

5.0 ESTIMATE OF THE PROJECT COST FOR IMPLEMENTING MODIFICATIONS

Based on the data derived from the heat balance tests, the heat efficiency of the kiln can be improved by retrofitting the system as given in Appendix F.

The estimated cost for Phases I, II, III and IV are given as follows:

Phase I

The cost of present pre-engineering survey is \$11,925.

Phase II

The estimate for carrying out the detailed engineering for retrofitting and upgrading the facility is \$200,000 spread over a period of 32 weeks. The detailed schedule and breakdown of the work to carry out the conceptual design for retrofitting and upgrading the facility is given in Figure 2.

Phase III

The retrofitting and upgrading of the facility involves revamping the cooler, changing the chain system in the kiln and modification of the equipment of the kiln. The estimated cost of carrying out these changes would be \$1,900,000. The detailed breakdown of the estimate is given in Table 2.

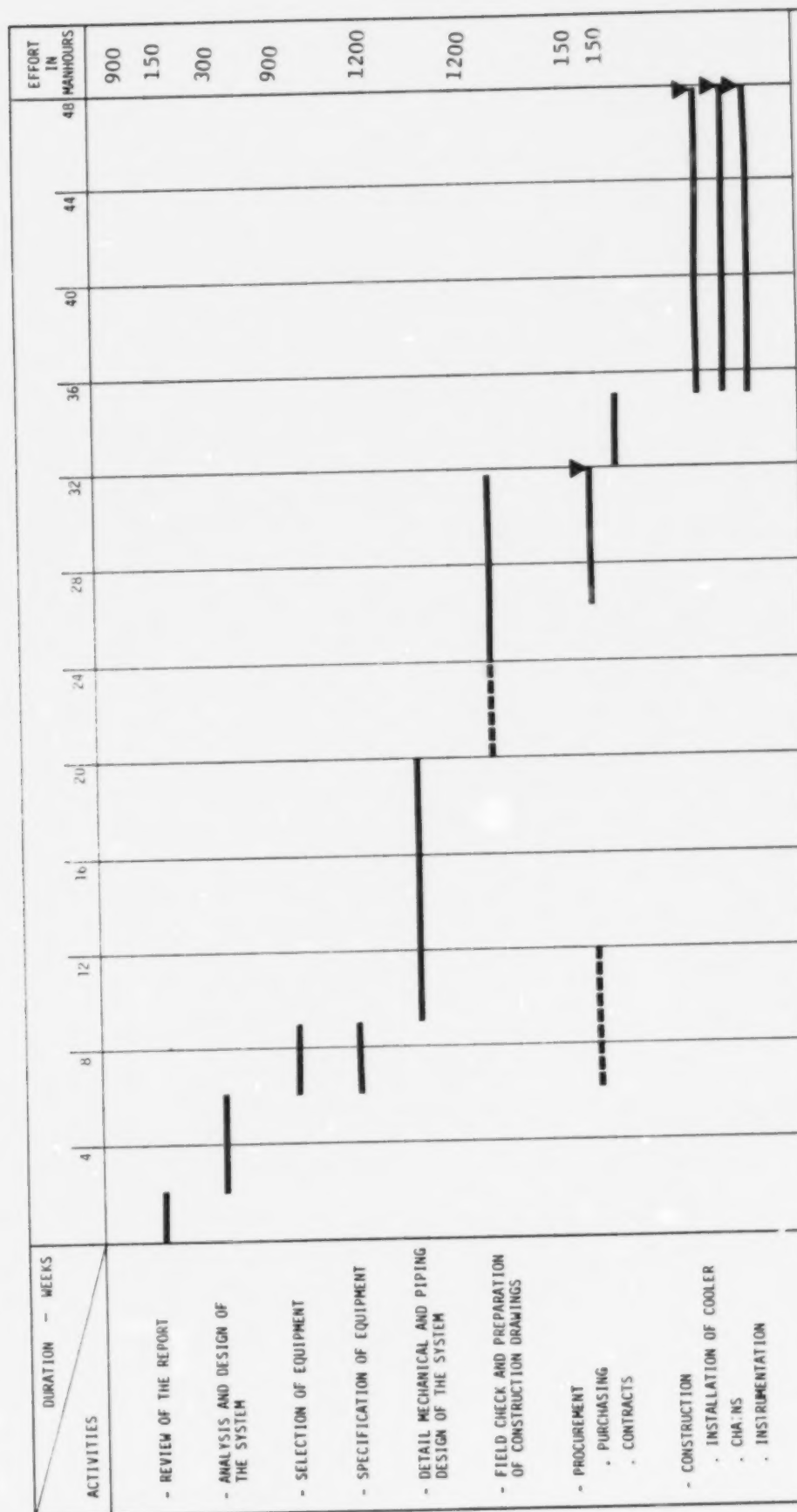
Phase IV

The estimated cost of the supervision and monitoring for nine months is \$80,000. This cost is based on employing one full time engineer for nine months. The cost includes his salary plus the overhead.

TABLE 2
DETAILED COST BREAKDOWN

ITEM	DESCRIPTION	\$
1	New chain system	750,000
2	Revamp cooler	850,000
3	Modificating equipments and kiln	120,000
4	Installation and site preparation	<u>180,000</u>
	TOTAL	<u>1,900,000</u>

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SCHEDULE FOR DETAIL ENGINEERING
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 FIGURE 2

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CONCLUSIONS

- a) The kiln specific fuel consumption is 918 kcal/kg clinker as compared with the lowest North American average of 997 kcal/kg clinker. This has been achieved as a result of the modifications incorporated to the kiln at the instance of the principal investigator of this study. Presently, there are 18 wet kilns and 6 long dry kilns in Canada, with an average specific consumption of 1200 kcal/kg clinker. If these kilns are retrofitted and upgraded by incorporating the same modifications, the average fuel consumption will be reduced to 950 kcal/kg clinker. This will enable the cement companies to save significant amounts of fuel, which when translated into dollar value, amounts to \$41,000,000 at the current price of \$35 to \$37 per barrel of fuel oil.
- b) The clinker cooler is inefficient. The clinker outlet temperature is 147°C, which is considered to be too high. Some amount of sensible heat can be recovered by cooling the clinker down to 70°C. This can be achieved by revamping the cooler.
- c) A large amount of false air entering the kiln reduces the amount of high temperature secondary air in the kiln. This decreases the amount of sensible heat recovered from the clinker. A saving of 50 kcal/kg clinker can be achieved if the air leaks are plugged and secondary air in the kiln is increased. Furthermore, estimated 50 kcal/kg clinker can be saved because of improved flame efficiency resulting from increased secondary air in the kiln. Hence, about 100 kcal/kg clinker can be saved by incorporating these changes. This translates into saving of \$1,000,000 for producing 500,000 tonnes of clinker. The estimate for the cost for upgrading the facility including this pre-engineering study is \$2,112,000. Hence, the ROI calculated, based on these numbers, is 47%.
- d) The clinker exiting from the cooler is too hot because of the low efficiency of the cooler. This requires more electrical energy in grinding and in some cases, the phenomenon of quick set may occur.
- e) The kiln chain system requires improvement.

7.0 RECOMMENDATIONS

- a) The kiln chain system should be redesigned to one which gives better specific surface to weight ratio.
- b) The clinker cooler should be revamped.
- c) Similar tests should be carried out on all the kilns erected across the country before 1975.

Based on the ROI value of 47% determined, it is recommended that the above mentioned improvements be carried out. They will bring substantial savings in fuel consumption and would yield attractive return on investment.

APPENDIX A
KILN DATA SHEET

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APPENDIX A

KILN DATA SHEET

Manufacturer : Allis-Chalmers, Milwaukee, Wi
Start-up date : February 1960

1 - KILN
dry process long kiln
Nominal capacity: 1500 metric tonnes per day
Total length : 550 ft. or 167.20 m.
Diameters :

Internal

External

on 707 feet	14 ft. or 4.256 m	15 ft. or 4.56 m
on 443 feet	13 ft. or 4.100 m	15 ft. or 4.56 m

Plate thickness :

per riding ring:	3" x 7' - 0" one plate
	3" x 5' - 0" two plates
clinker unit:	1 1/2" over 7' - 6"
burning zone:	1 1/8" over 60' - 0"
remaining:	1"

Slenderness $\frac{L}{D}$: 36.67

Slope : 7/16" per linear foot or 2°/5' 30"
or 3.65%

Rotating : Minimum 0.30 minute/revolution
Movement : Maximum 1.33 " "
Current 1.24 " "

Slow down 8 minutes/revolution
N.B.: 1.4 minute/revolution corresponds to the
Kiln natural resonance

Drive Motor : 2 x 220 H.P. (DC)
Daily Production: Capacity: 1200 to 1600 sh. tons of clinker
Piers and Tyres : 7 at 81 to 88 ft. distance from each other
Rollers : 72" x 34" in last steel with a forged steel shaft
24" in diameter and bronze bearings 24" x 26"

2 - Cooler
Original Specifications
Manufacturer : Allis-Chalmers
Type : Air quenching reciprocating conveying motion
Sections : 2 sections each 60 ft. (18.24 m) long
Capacity : 1660 tons/day
Cooling Air : 200 000 CFM (94.4 m³/sec) Max.
5 1/2" W.G. (140 mm) pressure and
70°F (20°C)

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APPENDIX A (cont'd)

Secondary Air Temperature: 1100 to 1300°F
Cold Air Fans : two mounted on same shaft at
567 RPM (presently at 268 RPM)

This cooler has been equipped in 1981 with a gravelfilter equipped with 4 cyclones followed by 14 gravel chambers with 130 mm layers of gravel. Each chamber is cleaned out each time by countercurrent compressed air during 4 minutes every 70 minutes. Suction speed is automatically controlled to give a regular depression of 0.12 inches of water.

3 - Crusher hammer crusher 7 1/2 ft. wide with
3 rows of 6 hammers 7 ft. each

4 - Electrostatic Precipitator

Manufacturer: Western Precipitation Co.
Type : RWS Cottrell preceded by a multicyclone type
24 IH with 2 rows 24" diameter tubes
Flue Gas Volumes: Approximately 276,000 CFM (7833 m³/mn) at 700°F
with a 10 grain dust content per cu.ft.
Flue Gas Humidity: 6 to 10% by weight
Number of Cells: South 3 sections and North 4 each with ducts at
10" distance
Electrodes: 0.1055" diameter steel wire with C.I. weights
Operation: Automatic with transistomatic controls
Temperature: 700°F or 371°C
Transformers: 8 full wave silicium, 500/50 000V, 60 cycles, 400 mA

5 - Water Atomization

Water: Max. 32 gpm or 145.5 lpmn.
Air : 175 CFM (4.956 m³/mn)
70 psi pressure

6 - I.D. Fans

Number: 2 (only the South one being used)
Max. 200,000 CFM or 5662 m³/m
6" static pressure WG or 152.4 mm
700°F or 371°C
567 R.P.M. (410 R.P.M.)
230 S.H.P.
245 HP including clutch coupling losses for
variable speed

7 - Cooler Air Fan (original data sheet)

238,000 CFM or 6739 m³/mn
5 1/2" W.G. static pressure
100°F
567 R.P.M. (during tests 268 R.P.M.)
273 HP including clutch losses

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APPENDIX A (cont'd)

8 - Kiln Chain System

This system is divided into two areas separated by a 7 feet chain free area. The first chain area is formed by 31 rows of chains, each row distant by 12" 7/8 from the other. The second chain area is formed by 15 rows of chains each with 12" 7/8 distance between 2 rows.

The following table gives a detailed description of the chain system with chain description in their new conditions.

9 - Primary Air Fan

14,400 C.F.M.
100 H.P.
27.7" max. static pressure
Dumper graduations from 0 to 11 (90°)

10 - Specific Values

Kiln capacity rating : 1500 T/24 hours
Kiln effective volume : 2262 m³
Kiln specific volume rating: 0.663 Ts/24 h. m³

Total chain surface area: 2468 m²
Chain specific area : 1.09 m²/m³

Total chain weight = 100,734 kgs
Specific chain weight = 67.156 kg/t clinker 24 hours

31C

APPENDIX A (cont'd)

TABLE A
KILN-A CHAIN SYSTEM

MIRON CO., INC.

(Chain Row Numbering Starts from Feed End) (Distance Between Each Row - 12" 7/8)

Area	Chain Row No.	No. of Chains for Row	Chain Maker	Type of Chains	Link dims. and Chain Length (New) inches	No. of Links per Chain	Year of Installation	Surface Area sq ft per ft length	Weight per ft length in lbs	Total Surface Area sq ft	Total Weight in lbs
A	1	45/45	Drummond McCall	C 1008	3/4 x 2 3/4	10	1974	0.785	6.5	353.25	2925
	2	85/85	Drummond McCall	C 1008	3/4 x 2 3/4	10	1974	0.785	6.5	667.25	5525
	3 to 6	80/320	Abex	C 1008	3/4 x 2 3/4	10	1974	0.785	6.5	2512.00	20800
	7 to 8	80/160	Dominion Chain	C 1008	3/4 x 2 3/4	10	1977	0.82	6.5	1312.00	10400
	9 to 13	80/400	Dominion Chain	C 1008	3/4 x 2 3/4	10	1974	0.82	6.5	3280.00	26000
	14 to 22	40/360	Keating	C 1008	3/4 x 2 3/4	10	1979	0.81	6.5	2916.00	23400
	23 to 25	80/240	Keating	C 1008	3/4 x 2 3/4	10	1979	0.81	6.5	1944.00	15600
	26 to 31	40/240	ABEX	HHe Oval	19/32x5/8x3	10	1974	0.99	8.45	2376.00	70352
	TOTAL	1850									
	32 to 36	80/400	DeM. Margotteaux	FMR 153	7/8 x 3	10	1979	0.93	8.27	3720.00	33080
B	37 to 39	80/240	ABEX	HH2	7/8 to 3/4 x 3	10	1980	0.85	7.00	2040.00	16800
	40 to 41	80/160	Lister	4742	6/8 x 3	10	1980	0.93	8.30	1488.00	13280
	42 to 46	80/400	ABEX	HH2 oval	19/32 x 5/8 x 3	10	1972	0.99	8.48	3960.00	33920
	TOTAL	1200								11208.00	97080
GRAND TOTAL		3050								sq ft 26568.00 or 2468 m ²	lbs 222080 or 100734 Kgs

APPENDIX A (cont'd)

11 - Data on Fuel Oil Used

A composite sample of the fuel oil used during the heat balance test was analyzed by Energy Mines & Resources, Canada laboratories in Ottawa and the following results were obtained:

Ultimate Analysis

C = 88.01%
H₂ = 9.42%
N₂ = 0.23%
S = 0.34%(by difference)

100.00%

Water Content: 0.2% volume
Ash Content : 0.04 approx.

Higher Calorific Value: 18,111.7 BTU/lb
= 10,063 kcal/kg fuel

Lower Value = 10063 - (50.54 x 9.24)
= 9597 kcal/kg fuel

Flash point (Prinsky-Martin closed cup): 216°F = 102°C

Kinematic viscosity at 100°F = 1.384 cSt
210°F = 34.76 cSt

Specific gravity at various temperatures are shown in graph.

APPENDIX B
OPERATING DATA FOR THE KILN

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APPENDIX B - OPERATING DATA FOR THE KILN

TABLE B-1
OPERATING CONDITIONS ON 2/12/82

OPERATING CONDITIONS ON 2/12/82																					
Hr.	KILN			Temp. of the Entry ESP °F	KILN OPERATION										Cooler Motor RPM	Cooler Grate Pressure "Water"	Temp. Secondary Air °F	Cooler Exhaust Fan RPM	Fan Pres. "Water"	Density of Clinker kg/l	
	RPM	Motor Amp. %	Entry T/H		Feed Temp. °F	Hood Temp. °F	O ₂ %	I.D. Fan RPM	Pres. Prim. Air "Water"	Temp. Chain End, °F	Kiln Shell #1 °F	Kiln Shell #2 °F	Fuel Rate l/m	Suction in Hood "Water"							Cooler Fan RPM
8.00	1.26	100	93.4	660	760	1.1	1.2	410	1.8	1,560	510	465	102	0.12	420	4.6	269	1,550	680	0.3	
9.00	1.26	100	93.4	655	760	1.2	1.2	410	1.8	1,570	510	500	102	0.12	420	4.6	270	1,600	650	0.3	
10.00	1.26	100	93.4	655	760	1.1	1.1	410	1.8	1,560	510	560	102	0.12	420	4.6	270	1,630	640	0.3	
11.00	1.26	100	93.4	655	760	1.1	1.0	410	1.8	1,570	550	570	102	0.12	420	4.6	270	1,510	640	0.3	
12.00	1.26	100	93.4	655	760	1.1	0.9	410	1.8	1,560	510	500	102	0.12	420	4.6	270	1,600	690	0.3	
13.00	1.26	100	93.4	660	760	1.1	1.0	410	1.8	1,570	510	510	102	0.12	420	4.6	270	1,610	640	0.3	
14.00	1.26	100	93.4	660	780	1.1	1.1	410	1.8	1,580	510	490	102	0.12	420	4.6	270	1,650	630	0.3	
15.00	1.26	100	93.4	655	775	1.1	1.0	410	1.8	1,580	515	500	102	0.12	410	4.6	268	1,700	640	0.3	
16.00	1.26	100	93.4	655	765	1.1	1.2	410	1.8	1,580	510	500	102	0.12	410	4.6	269	1,680	640	0.3	
17.00	1.26	100	93.4	660	770	1.1	1.3	410	1.8	1,580	510	500	102	0.12	420	4.6	270	1,660	650	0.3	
18.00	1.26	100	93.4	660	770	1.1	1.3	410	1.8	1,575	500	505	102	0.12	420	4.6	270	1,670	640	0.3	
19.00	1.26	95	93.4	660	780	1.1	1.0	410	1.8	1,575	500	510	102	0.12	420	4.6	270	1,710	640	0.3	
20.00	1.26	95	93.4	660	780	1.1	1.0	410	1.8	1,575	500	510	102	0.12	420	4.6	270	1,680	640	0.3	
21.00	1.26	95	93.4	660	780	1.1	1.0	410	1.8	1,588	500	505	102	0.12	420	4.6	270	1,740	640	0.3	
22.00	1.26	95	93.4	660	795	1.0	1.2	410	1.8	1,580	500	505	102	0.12	420	4.6	290	1,740	660	0.3	
23.00	1.26	95	93.4	660	800	1.0	1.4	410	1.8	1,580	510	505	102	0.12	420	4.6	267	1,700	660	0.3	
24.00	1.26	100	93.4	660	800	1.0	1.5	410	1.8	1,580	505	500	102	0.12	420	4.6	268	1,670	640	0.3	
01.00	1.26	100	93.4	660	800	1.0	1.2	410	1.8	1,580	500	500	102	0.12	420	4.6	267	1,670	660	0.3	
02.00	1.26	100	93.4	660	800	1.0	1.2	410	1.8	1,580	500	500	102	0.12	420	4.6	266	1,700	690	0.3	
03.00	1.26	100	93.4	660	810	1.0	1.1	410	1.8	1,580	500	495	102	0.12	420	4.6	266	1,720	670	0.3	
04.00	1.26	100	93.4	660	800	1.0	1.1	410	1.8	1,580	510	495	102	0.12	420	4.6	266	1,700	690	0.3	
05.00	1.26	100	93.4	660	800	1.0	1.1	410	1.8	1,580	510	495	102	0.12	420	4.6	266	1,720	670	0.3	
06.00	1.26	100	93.4	660	800	1.0	1.1	410	1.8	1,580	510	495	102	0.12	420	4.6	267	1,730	630	0.3	
07.00	1.26	100	93.4	660	795	1.05	1.7	410	1.8	1,580	510	504	102	0.12	420	4.6	268	1,666	879	0.3	
08.00	1.26	95	93.4	660	781	1.08	1.164	410	1.8	1,576	510	504	102	0.12	420	4.6	268	1,666	879	0.3	
Average	1.26	99	93.4	659	781	1.08	1.164	410	1.8	1,576	510	504	102	0.12	420	4.6	268	1,666	879	0.3	

APPENDIX B (cont'd)

TABLE B-2

RAW FEED METER READINGS

DATE	HOUR	READING IN TONNES	TOTAL TONNES
2/12/82	8h00	0770.8	
2/12/82	24h00	2242.1	1471.3
		Then set to zero	
3/12/82	0h00	zero	
3/12/82	8h00	0770.8	<u>770.8</u>
Total Meal in 24 hrs.			2242.1 tonnes
Equivalent to $\frac{2242.1}{24}$			= 93.42 t/h

APPENDIX B (cont'd)

TABLE B-3

FUEL OIL METER READINGS

DATE	HOUR	READINGS IN LITRES	TOTAL IN LITRES
2/12/82	8h00	50668	
2/12/82	24h00	148 140	97,672
		then set to zero	
3/12/82	0h00	Zero	
3/12/82	8h00	48891	<u>48,891</u>
Total in 24 hrs.			146,563

$$\text{Fuel Oil Average} = \frac{146563}{24 \times 60} = 101.78 \text{ l/m}$$

APPENDIX B (cont'd)

TABLE B-4
KILN TEMPERATURES

	TEMPERATURE INLET ESP.		TEMPERATURE FEED END		END OF CHAINS GAS		KILN SHELL #1		KILN SHELL #2		SECONDARY AIR	
	OF	OC	OF	OC	OF	OC	OF	OC	OF	OC	OF	OC
8.00	600	349	760	404.4	1560	848.8	510	265.5	465	240.5	1550	843.3
9.00	655	346	760	404.4	1570	854.4	510	265.5	500	260	1600	871.1
10.00	655	346	760	404.4	1560	848.8	510	265.5	540	282.2	1630	887.7
11.00	655	346	760	404.4	1570	854.4	510	287.7	570	298.8	1510	821.1
12.00	655	346	760	404.4	1560	848.8	510	287.7	500	260	1600	871.1
13.00	660	349	760	404.4	1570	854.4	510	287.7	510	265.5	1610	876.6
14.00	660	349	780	415.5	1580	860	510	287.7	490	254.4	1650	898.9
15.00	655	346	775	412.7	1580	860	510	287.7	490	254.4	1660	904.4
16.00	655	346	760	404.4	1580	860	515	265.5	510	265.5	1710	932.2
17.00	655	346	765	407.2	1580	860	510	265.5	500	260	1700	926.6
18.00	660	349	765	407.2	1580	860	510	265.5	500	260	1680	915.5
19.00	660	349	770	410	1575	872.2	500	260	505	262.7	1660	904.4
20.00	660	349	780	415.5	1575	872.2	500	260	510	265.5	1670	910
21.00	660	349	780	415.5	1575	872.2	500	260	510	265.5	1710	932.2
22.00	660	349	780	415.5	1575	872.2	500	260	510	265.5	1680	915.5
23.00	660	349	800	426.6	1588	864.4	600	315.5	505	262.7	1740	948.9
24.00	660	349	795	423.8	1580	860	500	260	505	262.7	1700	926.6
01.00	660	349	800	426.6	1580	860	510	265.5	505	262.7	1670	910
02.00	660	349	800	416.6	1580	860	505	262.7	500	260	1670	910
03.00	660	349	800	426.6	1580	860	500	260	500	260	1670	910
04.00	660	349	800	426.6	1580	860	500	260	500	260	1670	910
05.00	660	349	810	432.2	1580	860	500	260	495	257.2	1700	926.6
06.00	660	349	800	426.6	1580	860	510	265.5	495	257.2	1700	926.6
07.00	660	349	800	426.6	1580	860	510	265.5	495	257.2	1720	937.7
08.00	660	349	795	423.8	1580	860	510	265.5	495	257.2	1730	943.3
AVG.		348		417.3		860.1		270	504	262	1598	870

NOTE: Temperatures raised with secondary air temperature rise

APPENDIX C
RAW MIX AND DUST

APPENDIX C

RAW MIX AND DUST

We have been carefull to measure quantities and characteristics of Raw Meal fed to the kiln as well as the recycled filter dust and the discarded one.

The amounts of dust exiting from the electrostatic filter screw conveyors was weighed by loading it on trucks which were then weighed on the Miron weighbridge. This operation was carried out as follows:

1. For the discarded dust: Total dust collected from 15h00 on 1/12/82 to 15h00 on 2/2/82.

Total amount in 24 hours: 74.83 tonnes = 3.118 tph.

2. Recycled Dust:

Dust quantities were measured by using stopwatch from the 2 different discharging circuits with following results:

Screw No. 3: 98.1 lbs/35.24

Screw No.10: 172.5 lbs/35.24

Total 270.6 lbs/35.24

This brings the dust proportions:

Screw No. 3 = 36.25%

Screw No.10 = 63.75%

Hourly quantity of recycled dust: 12.565 metric tonnes.

APPENDIX C (cont'd)

TABLE C-1
COMPOSITE CHEMICAL ANALYSES

Composite Samples	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	L.O.I. 1050°C	Total	C ₂ S
<u>Raw Feed</u>											
8.00 to 14.00	13.88	3.29	1.82	40.74	2.98	0.90	0.92	0.25	34.60	99.38	
16.00 to 22.00	14.00	3.29	1.90	40.86	3.00	0.90	0.93	0.25	34.67	99.80	
0.00 to 6.00	14.03	3.25	1.91	41.02	2.90	0.90	0.94	0.25	34.75	99.95	
Average	13.97	3.28	1.88	40.87	2.96	0.90	0.93	0.25	34.67	99.71	
Erlin Hime Lab.	14.05	3.29	1.86	40.33	2.82	0.75	0.93	0.23	37.08*	101.34	
<u>Raw Feed Loss Free</u>											
8.00 to 14.00	21.36	5.06	2.76	62.68	4.59	1.38	1.42	0.38	-	99.63	
16.00 to 22.00	21.47	5.05	2.91	62.67	4.60	1.38	1.43	0.38	-	99.89	
0.00 to 6.00	21.51	4.98	2.93	62.90	4.45	1.38	1.44	0.38	-	99.97	
Average	21.45	5.03	2.87	62.75	4.55	1.38	1.43	0.38	-	99.83	
<u>Clinker</u>											Free CaO
8.00 to 14.00	21.20	4.82	2.86	62.72	4.23	1.55	1.30	0.35	-	99.03	0.21
16.00 to 22.00	21.34	4.87	2.86	62.81	4.02	1.60	1.30	0.36	-	99.16	0.21
0.00 to 6.00	21.32	4.82	2.86	62.52	4.43	1.53	1.30	0.30	-	99.08	0.21
Average	21.29	4.84	2.86	62.68	4.23	1.56	1.30	0.34		99.10	0.21
Erlin Hime Lab.	21.53	50.3	2.91	62.32	4.34	1.42	1.72	0.37	(2.49)*	99.64	

* L.O.I. carried out at temperature of 1300°C

APPENDIX C (cont'd)

TABLE C-2
CHEMICAL ANALYSES OF COMPOSITE DUST - SAMPLES

Composite Samples	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	K ₂ O	Na ₂ O	L.O.I.	Total	Free CaO
<u>Recycled Dust</u>											
10.00 to 16.00	14.47	2.98	1.87	43.08	2.97	3.78	1.68	0.38	27.22	98.43	4.31
18.00 to 24.00	14.42	2.92	1.88	43.09	3.01	4.00	1.68	0.38	26.90	98.28	4.81
2.00 to 8.00	14.56	2.86	1.99	43.30	3.45	4.00	1.68	0.38	26.74	98.96	4.98
Average	14.48	2.96	1.91	43.16	3.14	3.93	1.68	0.38	26.95	98.55	4.70
Erlin Hime Lab.	14.16	3.45	1.94	43.17	3.25	3.89	1.60	0.29	32.70*	104.45	
<u>Loss Free</u>											
10.00 to 16.00	20.40	4.16	2.61	60.14	4.15	5.28	2.35	0.53	-	99.42	
18.00 to 24.00	20.04	4.06	2.61	59.90	4.18	5.56	2.34	0.53	-	99.22	
2.00 to 8.00	20.08	3.94	2.74	59.73	4.76	5.52	2.32	0.52	-	99.61	
Average	20.14	4.05	2.65	59.92	4.41	5.45	2.34	0.53	-	99.42	
<u>Discarded Dust</u>											
10.00 to 16.00	12.03	3.59	1.63	42.41	1.75	4.66	2.94	0.52	28.98	98.51	
18.00 to 24.00	12.21	3.78	1.63	43.00	1.72	4.40	2.68	0.48	29.00	98.90	
2.00 to 8.00	12.07	3.64	1.68	42.46	1.95	4.97	2.88	0.50	28.68	98.83	
Average	12.10	3.67	1.65	42.62	1.81	4.68	2.83	0.50	28.89	98.76	2.61
Erlin Hime Lab.	12.54	3.79	1.59	42.45	1.97	4.21	2.72	0.43	(36.88)	106.58	
<u>Loss Free</u>											
10.00 to 16.00	17.20	5.13	2.33	60.62	2.50	6.66	4.20	0.74	-	99.38	
18.00 to 24.00	17.39	5.38	2.32	61.24	2.45	6.27	3.82	0.68	-	99.55	
2.00 to 8.00	17.12	5.16	2.38	60.24	2.77	7.05	4.09	0.71	-	99.52	
Average	17.24	5.22	2.34	60.70	2.57	6.44	4.04	0.71	-	99.48	

* L.O.I. carried out at a temperature of 1300°C

APPENDIX C (cont'd)

TABLE C-3

PHYSICAL ANALYSES

Time	Raw Feed			Discarded Dust		Recycled Dust				Clinker Free CaO %
	H ₂ O %	L.O.I. 1050°C %	Burning 1540°C %	L.O.I. 1050°C	Free CaO %	L.O.I.		Free Lime		
						Screw #3%	Screw #10%	Screw #3	Screw #10	
10.00		34.86	37.07	29.19		27.54	26.85			0.37
12.00		34.80	36.97	20.40		27.67	26.76			0.25
14.00		34.72	37.00	29.12		27.70	27.37			0.25
16.00	0.38	34.72	36.98	28.09		27.34	26.66			0.33
18.00	0.34	34.60	37.13	28.92		27.39	26.54			0.29
20.00	0.37	34.44	37.16	28.65		27.22	26.78			0.33
22.00	0.20	34.64	37.09	28.84		27.27	26.42			0.42
0.00	0.20	34.71	37.07	28.98		27.36	26.83			0.17
2.00	0.11	34.65	36.88	28.61		27.04	26.45			0.21
4.00	0.24	34.65	36.84	28.51		27.22	26.47			0.54
6.00	0.23	34.66	36.95	28.57		26.95	26.00			0.21
8.00	0.19	34.63	36.95	27.02		28.43	27.50			0.21
Average	0.25	34.67	36.92	28.66	2.16	27.43	26.72	4.70		0.30

APPENDIX C (cont'd)

TABLE C-4

MODULES AND MINERALOGICAL COMPOSITIONS
(on 24h averages)

	Raw Feed	Recycled Dust	Discarded Dust	Clinker
Si Modules	2.71	3.00	2.28	2.76
A/F	1.74	1.53	2.23	1.69
Kuehl S.F. (Potential)	0.928	0.957	1.091	0.933
Fluxing Index	25.27	-	-	26.20
Burnability Factor	2.94	3.11	3.49	3.13
C ₃ S	50.60	44.56	59.30	52.31
C ₂ S	23.34	24.05	4.70	21.78
C ₃ A	8.48	6.25	9.88	7.99
C ₄ AF	8.73	8.06	7.12	8.70

APPENDIX D
MATERIAL BALANCE CALCULATIONS

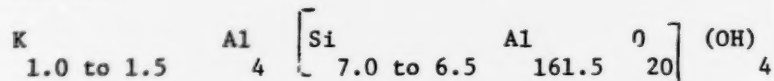
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APPENDIX D

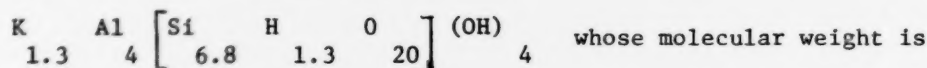
MATERIAL BALANCE CALCULATIONS

1.0 Kiln Raw Feed

Previous x-ray investigations carried out by Miron Co. of the kiln shale showed that the main silicate mineral in shell was illite with formula of:



We adopt the following average formula:



772.57, divided in the following oxides by weight:

<u>Oxide</u>	<u>M.Weight</u>
Al ₂ O ₃	270.28
SiO ₂	408.41
K ₂ O	61.22
H ₂ O	72.00

1.1 Considering the average analysis of the raw meal fed to the kiln, its mineralogical composition could be calculated as follows:

Illite:	$\frac{3.29 \times 772.57}{270.28}$	=	9.40%
Free Silica:	$13.97 - \frac{3.29 \times 408}{270.28}$	=	9.00%
Dolomite:	$\text{MgCO}_3 \frac{2.96 \times 84.32}{40.32}$	=	6.19%
	$\text{CaCO}_3 \frac{619 \times 100}{84.32}$	=	7.34%
Calcite:	$\frac{40.87 \times 100}{56} - 7.34$	=	7.43%
	Total		100.00%
H ₂ O in Illite:	$\frac{3.29 \times 35.35}{270.28}$	=	0.43% of raw meal

APPENDIX D (cont'd)

1.2 Calculation of CO₂ Evolving From Raw Meal

Specific consumption of raw meal:

93.43 t/h for a Clinker production of 62.05 t/h while discarded dust averages 3.118 t/h.

Specific consumption of raw meal is 1.5057 kg/kg clinker while discarded dust is 0.05 kg/kg clinker.

Loss on ignition of raw meal due to CO₂ = 34.67% - 0.43% = 34.24%.

CO₂ evolving from raw meal

$$1.5057 \times 0.3424 = 0.5156 \text{ kg/kg clinker}$$

CO₂ still present in discarded dust

$$0.05 \times 0.2889 = 0.0144 \text{ kg/kg clinker}$$

Net CO₂ present in flue gases and generated by raw meal calcination

$$0.5156 - 0.0144 = 0.5012 \text{ kg/kg clinker}$$

$$= \frac{0.5012 \times 22.4}{44} = 0.2552 \text{ Nm}^3/\text{kg clinker}$$

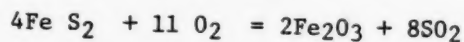
1.3 Water Vapour from Raw Meal

= Moisture in raw feed + chemical water in Illite

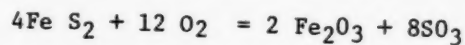
$$= 1.5057 (0.0025 + 0.0043) = 0.0102 \text{ kg/kg clinker}$$

$$= 0.0127 \text{ Nm}^3/\text{kg clinker}$$

Calculation of O₂ required for oxidation of FeS₂ to Fe₂O₃



We assume that 20% of the iron in the raw meal is present in a sulphite form i.e. $0.2 \times 0.0287 = 0.0057 \text{ kg/kg clinker}$.



$$\begin{array}{rcl} 12 \times 32 & = & (2(55.85 \times 2 + 3 \times 16) + 8 (32 + 32)) \\ 384 & & 319.4 \quad \quad \quad 512 \\ \times & & 0.0057 \quad \quad \quad \times \end{array}$$

$$\begin{aligned} \text{Therefore O}_2 \text{ consumed} &= 0.0069 \text{ kg/kg clinker} \\ &= 0.0048 \text{ Nm}^3/\text{kg clinker} \end{aligned}$$

APPENDIX D (cont'd)

$$\begin{aligned}\text{similarly } \text{SO}_3 &= 0.0091 \text{ kg/kg clinker} \\ &= 0.0032 \text{ Nm}^3/\text{kg clinker}\end{aligned}$$

Nitrogen from combustion air

$$\begin{aligned}\frac{0.0048 \times 79}{21} &= 0.0180 \text{ Nm}^3/\text{kg clinker} \\ = \frac{0.0180 \times 28}{22.4} &= 0.0225 \text{ kg/kg clinker}\end{aligned}$$

1.4 Water Atomization in Kiln

This water is used to cool down kiln flue gases before reaching the electrostatic filter.

Data

$$\begin{aligned}\text{Water flow rate: } 4.4 \text{ gpm} &= 20 \text{ litres/min.} \\ &= 1200 \text{ kg/h} = 0.0193 \text{ kg/kg clinker}\end{aligned}$$

Water inlet temperature 14°C

Compressed air rate: 300 CFM at 29 psi
Air temperature 17°C

Air volume of 300 CFM at 28 psi is equivalent to
 $510 \text{ m}^3/\text{h}$ at 28 psi and 17°C
 $915 \text{ Nm}^3/\text{h} = 0.0147 \text{ Nm}^3/\text{kg clinker}$
 $1178 \text{ kg/h} = 0.0190 \text{ kg/kg clinker}$

Ambient relative humidity 90%
Atmospheric pressure 1021.4 mbars

According to psychometric chart, water vapour in air amounts to 10.9 g/kg
 $= 12,840 \text{ kg vapour/hour}$
 $= 0.0023 \text{ kg/kg clinker}$

1.5 Sensible Heats at Kiln Inlet

$$\begin{aligned}\text{Enthalpy of moist air at } 17^\circ\text{C} &= 10.66 \text{ kcal/kg air} \\ &= 0.2024 \text{ kcal/kg clinker}\end{aligned}$$

$$\begin{aligned}\text{Enthalpy of atomized water at } 14^\circ\text{C} &= 14 \text{ kcal/kg water} \\ &= 0.2702 \text{ kcal/kg clinker}\end{aligned}$$

Total sensible heat at kiln inlet: $0.4726 \text{ kcal/kg clinker}$

APPENDIX D (cont'd)

2.0 Calculation of Clinker Production

2.1 By Stoichiometry

- Average raw feed on the 24 hours

$$\frac{2242.1}{24} = 93.43 \text{ t/h}$$
$$= 1.5057 \text{ kg/kg clinker}$$

- Discarded Electrofilter Dust

total 24 hours: 74.83 tonnes

Average per hour: 3.118 t/h
= 0.0502 kg/kg clinker

- Average Loss on Ignition (1400°C)

Raw Feed : 32.70%
Discarded Dust: 36.88%

- Theoretical Clinker Yield =

$$93.43 (1 - 0.327) - 3.118 (1 - 0.3688) = 60.91 \text{ t/h}$$

- 2.2 By Clinker Weighing: Kiln clinker production of 30 minutes and 60 minutes was loaded on trucks and weighed. Results were as follows:

<u>Date</u>	<u>Time</u>	<u>Minuted Output</u>	<u>Total Weight</u>
2/12	11 h 15	30 minutes	30.46 tonnes
2/12	13 h 30	30 minutes	33.62 tonnes
2/12	15 h 15	30 minutes	33.76 tonnes
3/12	7 h 30	30 minutes	31.93 tonnes
3/12	9 h 45	60 minutes	63.99 tonnes

The average Kiln output would be 64.59 t/h.

This figure seems exaggerated. We shall eliminate the 13 h 30 and 15 h 15 results which are certainly too high and consider only the balance whose average will be calculated as follows:

$$\frac{(30.46 + 31.93 + 63.99) \times 60}{30 + 30 + 60} = 63.19 \text{ t/h}$$

The raw feed scale might have an accuracy of $\pm 2\%$ as well as the truck weighbridge.

APPENDIX D (cont'd)

We therefore shall take the average of the obtained 2 values as our clinker output, i.e.

$$\frac{60.91 + 63.19}{2} = 62.05 \text{ t/h}$$

SPECIFIC VALUES

This rate brings the following ones:

Raw feed	1.5057 kg/kg clinker
Discarded dust	0.0502 kg/kg clinker
Recycled dust	0.2025 kg/kg clinker

2.3

CO₂ from Raw Feed:

CO₂ from raw feed: 0.3533 kg/kg clinker

APPENDIX D (cont'd)

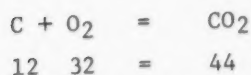
3.0 Flue Gas Material Balance

Fuel oil ultimate analysis

C	=	88.01%
H	=	9.24%
N	=	0.23%
S	=	2.18%
O	=	0.34% (by difference)

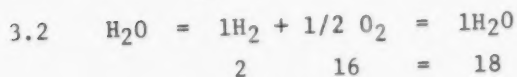
Combustion gases for an optimum combustion per kg of fuel

3.1 CO₂:



$$0.8801 \times \frac{44}{12} = 3.227 \text{ kg CO}_2/\text{kg fuel}$$

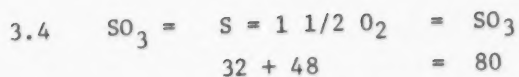
$$= \frac{3.22 \times 22.4}{44} = 1.6429 \text{ Nm}^3/\text{kg fuel}$$



$$\text{H}_2\text{O} = \frac{0.0924 \times 18}{2} = 0.8316 \text{ kg H}_2\text{O}/\text{kg fuel}$$

$$= \frac{0.8316 \times 22.4}{18} = 1.0349 \text{ Nm}^3/\text{kg fuel}$$

$$\begin{array}{rcl} 3.3 \quad \text{N}_2 & = & 0.0023 \text{ kg/kg fuel} \\ & & = \frac{0.0023 \times 22.4}{28} = 0.0018 \text{ Nm}^3/\text{kg fuel} \end{array}$$



$$\frac{0.0218 \times 80}{32} = 0.00545 \text{ kg/kg fuel}$$

$$\frac{0.0545 \times 22.4}{80} = 0.01526 \text{ Nm}^3/\text{kg fuel}$$

APPENDIX D (cont'd)

3.5 O₂ from air used for combustion:

$$\begin{aligned} - \text{ for CO}_2 &= \frac{0.8801 \times 32}{12} = 2.3469 \text{ kg/kg fuel} \\ - \text{ for H}_2\text{O} &= \frac{0.0924 \times 16}{2} = 0.7392 \text{ kg/kg fuel} \\ &= \frac{0.7392 \times 22.4}{32} = 0.5174 \text{ Nm}^3/\text{kg Fuel} \\ - \text{ for SO}_3 &= 0.0218 \times \frac{48}{32} = 0.0327 \text{ kg/kg fuel} \\ &= \frac{0.0327 \times 22.4}{32} = 0.0229 \text{ Nm}^3/\text{kg fuel} \end{aligned}$$

Total O₂ from air for optimum combustion

$$\begin{aligned} 2.3469 + 0.7392 + 0.0327 &= 3.1188 \text{ kg/kg fuel} \\ 3.1188 \times \frac{22.4}{32} &= 2.1832 \text{ Nm}^3/\text{kg fuel} \end{aligned}$$

3.6 Corresponding N₂ in combustion air:

$$\begin{aligned} \frac{2.1832 \times 0.79}{0.21} &= 8.2130 \text{ Nm}^3/\text{kg fuel} \\ = \frac{8.2130 \times 28}{22.4} &= 10.2662 \text{ kg/kg fuel} \end{aligned}$$

$$\begin{aligned} \text{Total combustion air} &= 13.3850 \text{ kg/kg fuel} \\ &= 10.3962 \text{ Nm}^3/\text{kg fuel} \end{aligned}$$

APPENDIX D (cont'd)

TABLE D-1

FLUE GAS COMPOSITION FOR NORMAL COMBUSTION

	Weight kg/kg Fuel	Volume Nm ³ /kg Fuel	% by Volume
CO ₂	3.2270	1.6429	15.06%
H ₂ O	0.8316	1.0349	9.49%
SO ₃	0.0545	0.0153	0.14%
N ₂ (in fuel)	0.0023	0.0018	
	<u>10.2662</u>	<u>8.2130</u>	<u>75.31%</u>
TOTAL	14.3816	10.9079	100.00%

APPENDIX D (cont'd)

TABLE D-2

ORSAT TEST RESULTS

(gas samples were taken at the kiln feed end)

Time	CO ₂ %	O ₂ %	CO %
8h00	28.8/28.8	1.2/1.2	0
9h45	28.8/29.0	1.2/1.2	0
11h45	30.0/28.8/28.8	0.2/1.4/1.4	0
12h45	28.4/30.2	1.8/1.0	0
14h00	29.2/28.8	1.6/1.6	0
16h00	29.5/29.5	1.4/1.4	0
18h00	30.2/30.2	1.4/1.4	0
20h00	20.3/29.3	1.4/1.4	0
22h00	30.3/30.3	1.4/1.4	0
0h00	28.4/28.4	1.6/1.6	0
2h00	29.2/29.2	1.4/1.4	0
4h00	28.9/28.9	1.6/1.6	0
6h00	28.8/28.8	1.8/1.8	0
8h00	29.6/29.6	1.2/1.2	0
AVERAGE	29.86	1.40	0
SAY	30.00	1.40	0

APPENDIX D (cont'd)

TABLE D-3

SPECIFIC FUEL CONSUMPTION
0.09535 kg Fuel/kg Clinker

Using the balance in D-1 for weight and volume of combustion gases expressed per kg Fuel, we shall express them hereafter in value of one kg of clinker produced.

Gas	By Weight		By Volume		In Orsat Test % Volume
	kg/kg Fuel	kg/kg Clinker	Nm ³ /kg Fuel	Nm ³ /kg Clinker	
CO ₂	3.2270	0.3077	1.6429	0.1566	15.08
H ₂ O	0.8316	0.0793	1.0349	0.0987	9.50
N ₂ (in fuel combustion)	0.0023	0.0002	0.0018	0.0002	75.42
	10.2662	0.9788	8.2130	0.7831	
TOTAL FUMES	14.3271	1.3663	10.8926	1.0386	100.00
For optimum combustion air required	13.3850	1.2813	10.3962	0.9952	-
SO ₃ before combining with alkalies	0.0545	0.0042	0.0153	0.0015	-

N.B. SO₃ does not exist as free gas in the fumes. It combines immediately with Na₂O, K₂O and CaO

TABLE D-4
GAS BALANCE A KILN EXIT (PUMPE CHAMBER)

(Actual case from gas analysis during the testing period)

Gas	Origin	By Weight in kg/kg Clinker			By Volume in Nm ³ /kg Clinker		
		Details	Total	Absolute %	Details	Total	Absolute %
CO ₂	Combustion Raw Material	0.4077	0.8089	38.07	0.1566	0.4118	27.28
		0.5012			0.2552		
N ₂	From combustion air Air S oxidation Air Atomization H ₂ O Excess Air Misc. (S oxidation & org. matter)	0.9788	1.1780	55.44	0.7864	0.9432	62.37
		0.0225			0.0180		
O ₂	From air atomization Excess Air	0.0145	0.0274	1.29	0.0116	0.0192	1.40
		0.0747			0.0609		
Water Vapour	Combustion Raw meal moisture Water atomization Excess air moisture	0.0874	0.1102	5.19	0.0031	0.1173	9.08
		0.0044			0.0161		
SO ₃ *	Combustion S in raw materials	0.0796	0.1102	5.19	0.0991	0.1173	9.08
		0.0102			0.0127		
		0.0193	0.0133	100.00	0.0242	1.5123	100.00
		0.0011			0.0013		
		0.0042	0.0133	100.00	0.0015	0.0047	0.0047
		0.0091			0.0012		

* SO₂ does not exist as a gas at kiln exit.

APPENDIX E
HEAT BALANCE CALCULATIONS

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APPENDIX E

1.0 Heat Balance Calculations

1.1 Fuel Consumption

a. Technical Data

Specific gravities: shown in attached graph at various temperatures.

Gross Calorific Value: 10,063 kcal/kg fuel

Net Calorific Value : 9,597 kcal/kg fuel

b. Fuel Consumption

- From meter: average over 24 hrs.
102 l/minute at 105°C
= 102 x 0.9565 = 97.563 kg/m

- From tanks: 2 tanks
each diameter 29 ft = 8.8392 m
height 24 ft = 7.315 m

For each of the 2 tanks, section area = 61.3644 m²

Measurement:

on 2/01/83 at 8h00	East	52" at 145°F
	West	52" at 158°F

on 3/01/83 at 8h00	East	99" 7/8 at 145°F
	West	98" 1/4 at 158°F

Difference:

$$\frac{99" 7/8 + 98" 1/4}{2} - 52 = 47.07" \text{ at } 152^{\circ}\text{F}$$
$$= 1.1956 \text{ m at } 66.7^{\circ}\text{C}$$

$$\begin{aligned} \text{Volume consumed: } & 61.3644 \times 1.1956 = 146.735 \text{ m}^3 \text{ at } 66.7^{\circ}\text{C} \\ & = \frac{146.735}{24 \times 60} = 101.90 \text{ litres/m} \\ & = 101.90 \times 0.98 = 99.86 \text{ kg/m} \end{aligned}$$

We shall take a mean value of 99.00 kg/m

APPENDIX E (cont'd)

c. Specific Consumptions

c.1 Sp. heat consumption of Kiln is therefore

$$\frac{99.0 \times 9,597 \times 60}{62,050} = 918.71 \text{ kcal/kg clinker}$$

Maximum consumption - 932 kcal/kg clinker
if we consider production of 60.92 t/h and
fuel consumption of 99.66 kg/m

c.2 Sp. Oil Consumption:

$$\frac{99.0 \times 60}{62050} = 0.09573 \text{ kg Fuel/kg clinker}$$

c.3 Sensible Heat of Oil

Oil temperature: 105°C

Sensible Heat: $0.09573 \times 105 \times 0.5 = 5.03 \text{ kcal/kg clinker}$

APPENDIX E (cont'd)

2.0 Heat Exchange in Cooler

2.1 Clinker:

Total amount of clinker: 62050 kg/h
Clinker temperature at cooler outlet: 156°C
Clinker temperature at cooler inlet: 1300°C
Clinker specific heat at 1300°C: 0.266 kcal/kg °C
at 156°C: 0.203 kcal/kg °C

Sensible heats of clinker	kcal/kg clinker
at cooler inlet: $1 \times 0.266 \times 1300 =$	345.80
at cooler outlet: $1 \times 0.203 \times 156 =$	<u>31.67</u>
Heat dissipated by cooler	314.13 kcal/kg clinker

2.2 Cooling Air Estimation

Our mean inlet temperature 12°C
Mean relative humidity 90% (7.8 g/kg air)
Atmospheric pressure 1021.4 m bars

- Mean temperature of air:

exhaust air 145°C
secondary air 870°C

- Enthalpies of water vapour: kcal/kg vapour

at: 12°C (from tables) = 44.5
145°C = $[100 + 538.7 + (0.468 \times 45)] = 659.76$
870°C = $[100 + 538.7 + (0.501 \times 770)] = 1024.47$

- Specific heat capacities of air at constant pressure

at 12°C = 0.231
145°C = 0.242
870°C = 0.2705

- Sensible heats of air

at 12°C = $[0.9920 \times 12 \times 0.231] + [0.0080 \times 44.5] = 3.11$
145°C = $[0.9920 \times 145 \times 0.242] + [0.0080 \times 659.76] = 40.09$
870°C = $[0.9920 \times 870 \times 0.2705] + [0.0080 \times 1024.47] = 241.65$

APPENDIX E (cont'd)

2.3 Air Flow Through Cooler

- 2.3.1 Air exiting from cooler could not be accurately measured by pitot tube due to flow turbulence. However, results indicate an approximate figure of $3.4 \text{ Nm}^3/\text{kg}$ clinker.
- 2.3.2 On the other hand, no fan chart corresponding to the existing operating conditions was available for the cooler main fan whose normal RPM was supposed to be 567 RPM, while actual was 268 RPM. However, by comparing with similar fans, a value of $3.1 \text{ Nm}^3/\text{kg}$ clinker was assumed.
- 2.3.3 On checking with the final balance sheet, we found that a reasonable value for secondary air admitted in kiln is about 0.8820 to 0.8850 kg/kg clinker.

For the sake of the test, we shall assume a total of $3.1 \text{ Nm}^3/\text{kg}$ Clinker to be entering the cooler.

The split between secondary air and exhaust can be calculated as follows:

Assuming:

x = weight of secondary air in kg/kg clinker
 y = weight of cooler exhaust air kg/kg clinker

5% of heat lost in cooler through cooler walls

Total heat content in cooler air from clinker
 $0.95 \times 345.8 = 328.51 \text{ kcal/kg clinker}$

. By Heat Balance:

$$\begin{aligned} x \times 241.65 + Yx \ 40.09 &= 328.51 \text{ kcal/kg clinker} \\ x + y &= 3.1 \text{ Nm}^3 \times 1.2875 = 3.9912 \text{ kg air/kg clinker} \end{aligned}$$

$$\text{exhaust air: } y = \frac{635.96}{201.56} = 3.1552 \text{ kg air/kg clinker}$$

$$\text{secondary air: } x = 0.8360 \text{ kg air/kg clinker}$$

Heat content of secondary air:

$$0.8360 \times 241.65 = 202.02 \text{ kcal/kg clinker}$$

Heat content of exhaust air:

$$3.1552 \times 40.09 = 126.49 \text{ kcal/kg clinker}$$

SIC

APPENDIX E (cont'd)

2.4 Air at Burner End

Total air entering the kiln burner end can be calculated from N_2 in Table D-4. It includes false air primary and secondary air.

$$N_2 = 0.7864 + 0.0180 + 0.0609 + 0.0663 = 0.9316 \text{ Nm}^3/\text{kg clinker}$$

$$\begin{aligned} \text{Corresponding air: } \frac{0.9316}{0.79} &= 1.1792 \text{ Nm}^3/\text{kg clinker} \\ &= 1.5182 \text{ kg/kg clinker} \end{aligned}$$

Therefore, the proportion of secondary air to total air entering kiln burner end

$$\frac{0.8360 \times 100}{1.5182} = 55.07\%$$

This figure is too low for a heat saving operation of kiln. It should be between 85% and 94%.

2.5 Heat Which Could Have Been Recuperated

$$(0.90 - 0.5507) \times 1.5182 \times 241.65 = 128.15 \text{ kcal/kg clinker}$$

2.6 Heat Content of Primary Combustion Air and False Air:

$$[1.5182 - 0.8360] \times 3.11 = 2.12 \text{ kcal/kg clinker}$$

2.7 Special Test for False Air

In order to have an indication of false air in kiln using the existing measuring means, a special test was carried out. Oxygen was gradually put down in kiln until CO started to appear on the Orsat. Gas analysis gave them 0.7% O_2 with 0.2% CO.

The volume of false air at this moment can be calculated from Table D-4 as follows:

$$0.007 \frac{[1.51223 - 0.0242 - 0.0013 - 0.0193 - 0.609 - 0.0116]}{0.21}$$

$$= 0.0465 \text{ Nm}^3/\text{kg clinker}$$

Volume of air entering kiln at this time can be calculated from N_2 balance in Table D.4.

$$\frac{0.9432 - 0.0609 - 0.0116}{0.79} = 4.26\%$$

This figure does not include false air entering through seal at kiln feed end.

APPENDIX E (cont'd)

3.0 Heat Balance of Raw Materials and Dust

3.1 Heat Content of Raw Materials and Dust & Clinker

3.1.1 Determination of Heat Capacities

Heat capacities at constant pressures were calculated for each temperature from formulae given in Perry's Chemical Engineering Handbook.

Heat capacities C_p expressed in cal/degree celsius/mole

$$CO_2 : 10.34 + 0.00274 T - 195500/T^2$$

$$N_2 : 6.50 + 0.00100 T$$

$$CO : 6.60 + 0.00120 T$$

$$O_2 : 8.27 + 0.000258 T - 187700/T^2$$

where T = absolute temperature in degrees Kelvin

Dry air heat capacities are calculated from those of O_2 and N_2 using a proportion of 23.30% to 76.70% by weight.

For solids, the following formulae were used:

$$CaCO_3 : 19.68 + 0.001189 T - 307600/T^2$$

$$CaSO_4 : 18.52 + 0.02197 T - 156800/T^2$$

$$Fe_2O_3 : 24.72 + 0.01604 T - 423400/T^2$$

$$MgCO_3 : 16.9$$

$$K_2SO_4 : 63.1$$

$$SiO_2 : 10.87 + 0.008712 T - 241200/T^2$$

$$Na_2SO_4 : 32.8$$

Concerning water vapour, enthalpy values were taken from tables in handbook or calculated.

3.1.2 Raw Meal

Feed temperature:	35°C
Feed rate	1.5057 kg/kg clinker
Sensible Heat	$1.5057 \times 0.245 \times 35 = 12.9111$ kcal/kg clinker

APPENDIX E (cont'd)

3.1.3 Discarded Dust

Outlet temperature: 668°C
Discharge rate: 3.118 t/h = 0.0502 kg/kg clinker
Sensible heat: $0.0502 \times 0.257 \times 668 = 8.6181$ kcal/kg clinker

3.1.4 Loss of Heat of Recycled Dust

Outlet temperature: 348°C
Inlet temperature average: #3 to #10 = 200°C
Rate of recycled dust: 0.2025 kg/kg clinker

Feed sensible heat: $0.2025 \times 0.257 \times 200 = 10.41$ kcal/kg clinker
Exit sensible heat: $0.2025 \times 0.257 \times 348 = 18.11$ kcal/kg clinker

3.1.5 Clinker

Outlet temperature from cooler: 156°C
Outlet temperature from kiln : 1300°C
Kiln discharge rate: 1 kg/kg clinker

Sensible Heat

	kW/kg
at kiln outlet:	345.80
at cooler outlet	<u>31.67</u>

Heat dissipated by cooler 314.13 kcal/kg
(heat partly recuperated by secondary air)

3.1.6 Heat of Formation of Clinker

This heat of formation is calculated in detail in a Miron Company internal report for the same raw materials. It is based on mineralogical composition. Its net value is 352 kcal/kg clinker.

APPENDIX E (cont'd)

3.2 Heat Content of Kiln Fumes

From composition of fumes given in Table D-1, the heat content of kiln outgoing fumes is calculated as follows:

3.2.1 Specific heat capacities of fumes at 417°C calculated from
3.1.1: kcal/kg gas °C

CO ₂ :	0.269
O ₂ :	0.252
N ₂ :	0.257

417°C is the mean temperature of kiln fumes at kiln feed end.

3.2.2 Heat Content of Fumes kcal/kg clinker

CO ₂ :	89.85
O ₂ :	2.88
N ₂ :	126.14
Water vapour: 0.1112 =	<u>88.58</u>

Total Heat Capacity = 307.45 kcal/kg clinker

TABLE F-1
LOSSES THROUGH KILN SHELL

$$\left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right]$$

Heat Losses by Radiation = $H_r = C \times S$

Heat Losses by Convection = $H_c = a \times S (t_1 - t_2)$

Other Data:

Ambient Temperature $17^\circ\text{C} = 290^\circ\text{K}$

Kiln External Diameter 15 ft = 4.572 m

Kiln Perimeter: $D = 3.14 \times 4.572 = 14.36 \text{ m}$

$C = 4.0$ for kilns

S = Surface area of Shell

T_1 and T_2 absolute temperature of Shell and ambient in $^\circ\text{K}$

t_1 and t_2 = temperature in $^\circ\text{C}$

$a = 5.3 + 3.6 V = 8.9 \text{ kcal/h/m}^2/^\circ\text{C}$

$V = 1 \text{ m/s}$

Zone Identification	Section Length		Surface Area m ²	Average Shell Temperature		$\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4$	Heat Loss By Radiation kcal/h	Heat Loss By Convection kcal/h	Total Heat Loss kcal/h
	ft	m		$^\circ\text{C}$	$^\circ\text{K}$				
Fume Chamber	15½ x 10 x 9	4.72 x 9.14 x 2.74	180	95	368	112.67	81,122	124,956	318,143
Preheating a Chain	132	40.234	578	132	405	198.31	458,493	591,581	928,615
Calcination	158	48.158	691	140	413	220.21	608,660	756,437	1257,612
Burning	260	79.248	1138	180	453	350.48	1594,930	1650,897	3138,490
TOTAL	550	167.640	2587				2743,205	3123,871	5867,076

Rated per kg clinker these losses are: $\frac{5,867,076}{6,2050} = 94.55 \text{ kcal/kg clinker}$

APPENDIX E (cont'd)

4.0 Heat Absorbed by Water Spray

A test was carried out to determine practically the amount of heat absorbed by the water spray at the kiln feed end.

The exit gas temperature at kiln fume chamber went up from 410°C to 488°C after the water spray was stopped.

Using fumes balance as per Table D-4 and gas heat capacities from Perry's handbook, the sensible heats of the various components of the kiln flue gases are calculated as follows:

1. At the normal exit temperature of 410°C:

$\text{CO}_2 = 0.8010 \times 0.2425 \times 410 =$	kcal/kg clinker
	79.64
$\text{N}_2 = 1.177 \times 0.249 \times 410 =$	120.15
$\text{O}_2 = 0.0274 \times 0.2325 \times 410 =$	2.61
$\text{Water Vapor} = 0.112 [100 + 538.7 + 0.480 (410-100)]$	
=	87.57

Total Heat Content at 410°C =	289.97 kcal/kg clinker
-------------------------------	------------------------

2. At reactor temperature after water jet was stopped:

$\text{CO}_2 = 0.8010 \times 0.2475 \times 488 =$	96.74
$\text{N}_2 = [1.177 - 0.0143] \times 0.251 \times 488 =$	142.39
$\text{O}_2 = [0.0227] \times 0.236 \times 488 =$	2.61
$\text{Water vapor} = [0.1112 - 0.0193]$	
$[100 + 538.7 + 0.4835 \times 388] =$	75.93
	317.67

3. Heat absorbed by spray: $317.67 - 289.97 = 27.7$ kcal/kg clinker

APPENDIX F

CONCEPTUAL PLAN FOR RETROFITTING
AND UPGRADING THE FACILITY

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APPENDIX F

CONCEPTUAL PLAN FOR RETROFITTING AND UPGRADING THE FACILITY

The following modifications will have to be made to increase the heat efficiency of the kiln.

- a) Install new chain system in the kiln. The chain system improves the heat transfer in the kiln. The new chain would increase the specific area of contact between flue gases and kiln feed and thereby improve the heat efficiency of the kiln. In the new chain system, the length of the chains, as well as the link design, have been improved to offer the maximum heat transfer area between gases and solid.
- b) Revamp the clinker cooler. The present cooler is very old and has many leaks. Therefore, it is not able to cool the clinker sufficiently and also consumes higher amount of cooling air. The cooler can be revamped by modifying the grate design, so as to offer better area of contact by proper solid distribution. The air distributor and the blower fans have to be changed in order to get a good heat transfer co-efficient. Many leaks were located in the cooler shell which will have to be plugged.
- c) Plug all the leaks in the kiln. These allow the air to leak into the kiln, reducing the sensible heat recovery from the kiln cooler. This is because the air leaking into the kiln reduces the amount of hot secondary air in the kiln. Decreasing the secondary air reduces the incandescence of the flame and the temperature of the flame and thereby reducing the heat transfer by radiation. Hence, plugging the leaks in the kiln is a very important retrofitting activity. Some of the leaks may be unavoidable, however, they have to be minimized, so as to improve the fuel efficiency of kiln.

The above mentioned modifications will lead to an estimated energy saving of 100 kcal/kg clinker.

POOR

QUALITY

ORIGINAL

